A Brain Transplant for Goofy Giggles

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Movie clip with new brain

1 Introduction

We describe the experimental platform we are developing for a redesigned H335 "Computer Structures" course that will emphasize the link between high level language execution and its realization at the ISA level. The goals and philosophy of this course will be discussed in a separate document. The primary objective for our laboratory platform is to provide a compelling ongoing design example in which to explore the ideas presented in lecture. These ideas include the interface between C and an instruction set architecture (ISA), execution contexts, event and I/O handling, real time programming, and the CPU as an ISA interpreter.

I (GB) felt that a laboratory based upon robots would provide a fun and compelling platform for student projects – this is in line with what many other schools have done however, I wanted to avoid a situation where topics from robotics dominate the course (e.g. vision, path planning, motion control, etc.). This meant that the basic application had to be easy to understand with minimal additional material – hence the choice to focus on line following robots. Although the basic function of line following can be realized with a simple control loop; we're developing a somewhat enriched platform that is capable of inter-robot communication and sound generation. This enriched platform provides the opportunity to introduce more sophisticated systems programming topics such as event handling and DMA based I/O.

In choosing a platform, I wanted to avoid the traditional laboratory model in which students have an assigned time in which to access shared lab platforms. In particular, I set as a goal developing a platform that is sufficiently cheap for each student to have exclusive use of one for the semester (in practice we may have pairs of students work together), and which is sufficiently robust that we can expect most platforms to survive over six or more semesters. I found that most of the available robot platforms are either too expensive or too fragile to meet this goal.

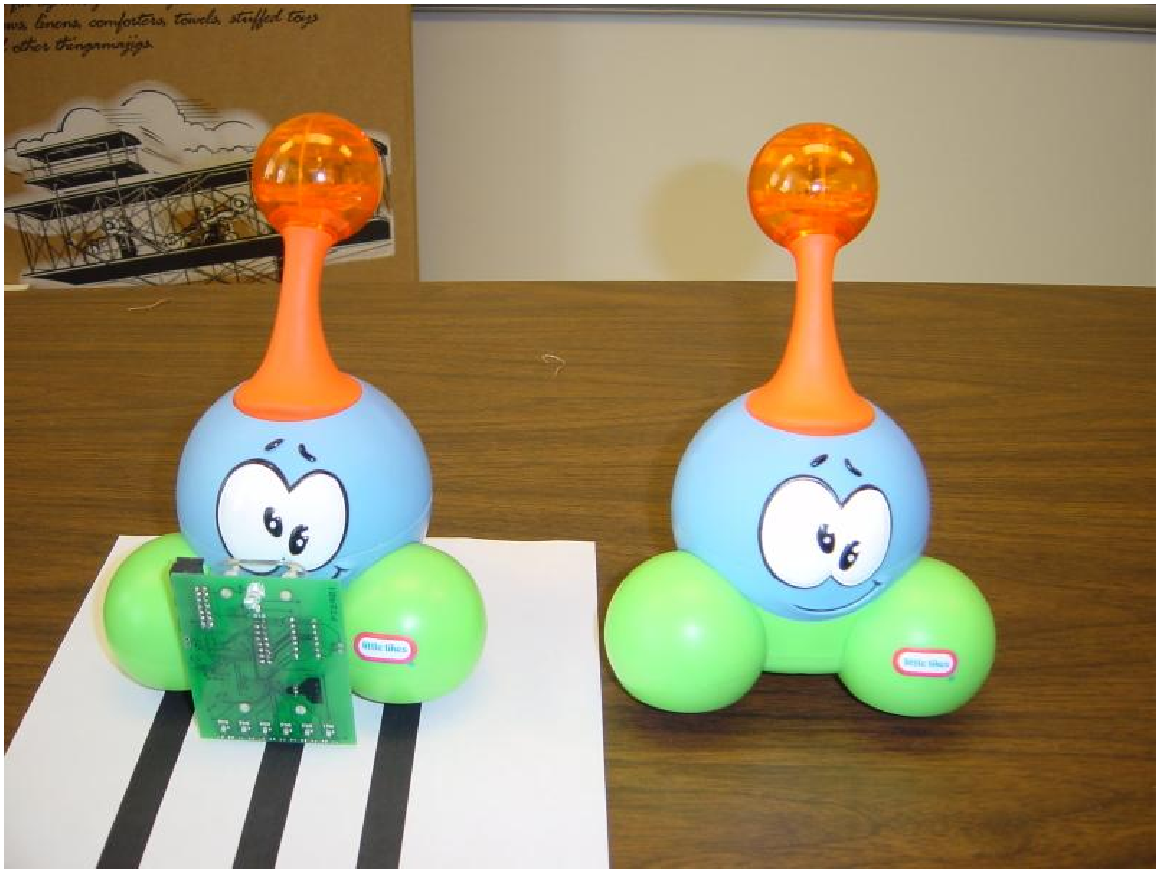
We decided to develop our platform based upon a toddlers toy – "Goofy Giggles" by Little Tikes. This is an amazingly robust and inexpensive toy which has the following basic I/O devices – a separate three-button infrared remote control, an infrared detector to receive commands, a pair of motors which independently drive the two wheels through a pair of gear boxes (there is a third free caster), and a small speaker. The toy is designed to be robust in the face of operator error – the arrangement of the wheels allows the toy to rotate within the diameter of the wheels and castor which makes it hard to get the toy stuck, and the design of the IR detector allows for very imprecise aiming of the remote control. In addition, it is designed to survive rough handling by the 6 month – 3 year age group; for example, the gear boxes are protected by slip clutches which prevent damage when the toy is pushed and the motors are protected from stall currents.

For our brain transplant, we chose to replace the internal electronics of the toy with an external board. In addition to providing access to all of the built-in I/O devices of the toy, this board provides the additional sensors required to perform line following, switches and LEDs for debugging and preliminary experiments,an infrared emitter for inter-robot communication, and a large serial flash memory for storing music and data logging. The processor on this external board is an MSP430 which we chose because it has an ISA that meets our course objectives, it has good support for in-circuit programming and debugging, it is supported by a full GNU toolchain, and it has a rich set of I/O devices.

In the remainder of this document we describe Goofy Giggles and its brain transplant in more detail. Finally, we outline our proposed sequence of laboratory experiments.

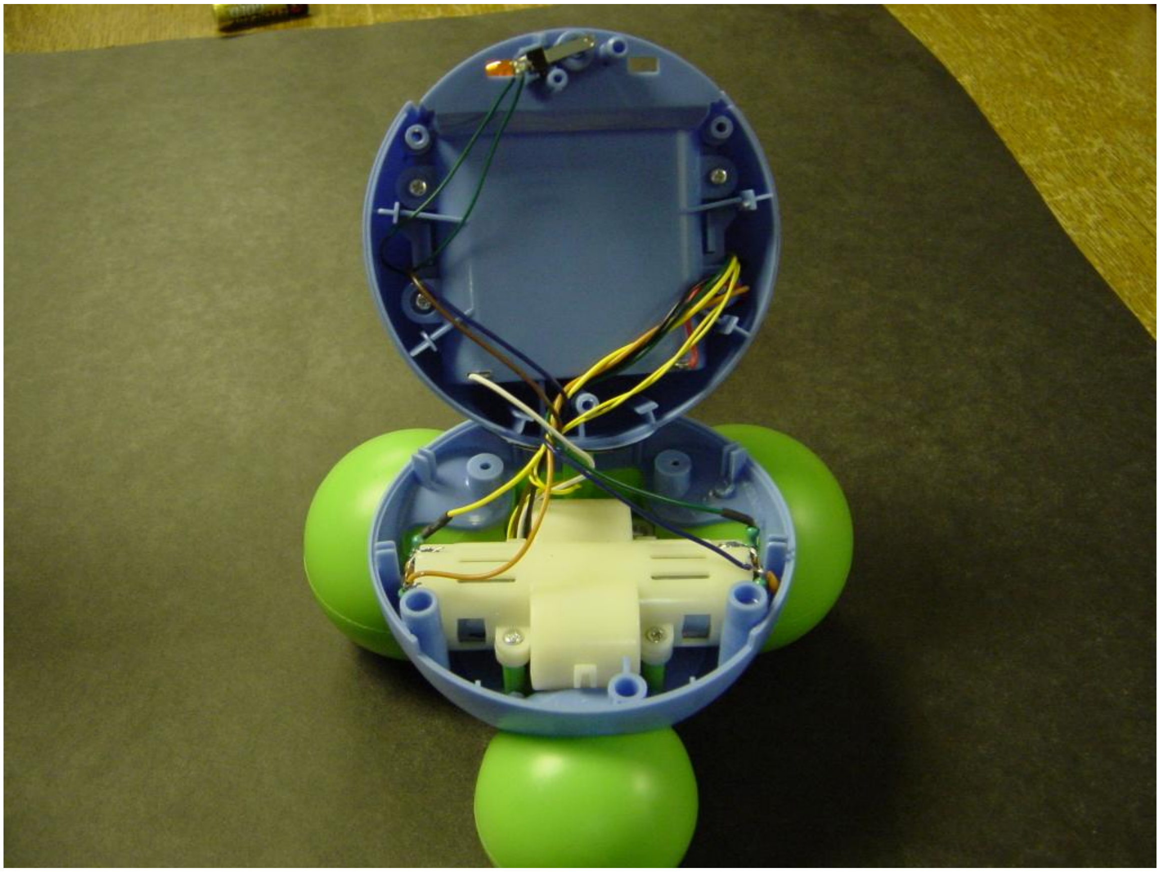
2 Goofy Giggles

The two versions of Goofy Giggles are illustrated in the following photograph. The modified Goofy is shown on the left on top of a test page with three lines. As we shall show, the external circuit board is mounted on an acrylic bracket attached to the base of Goofy Giggles and is interfaced through a ribbon cable to the internal I/O devices. An important component of Goofy Giggles is the IR detector which is contained the orange ball on top; this detector has a well designed optical system consisting of a conical mirror which makes the system very robust in the face of mis-aiming of the control.

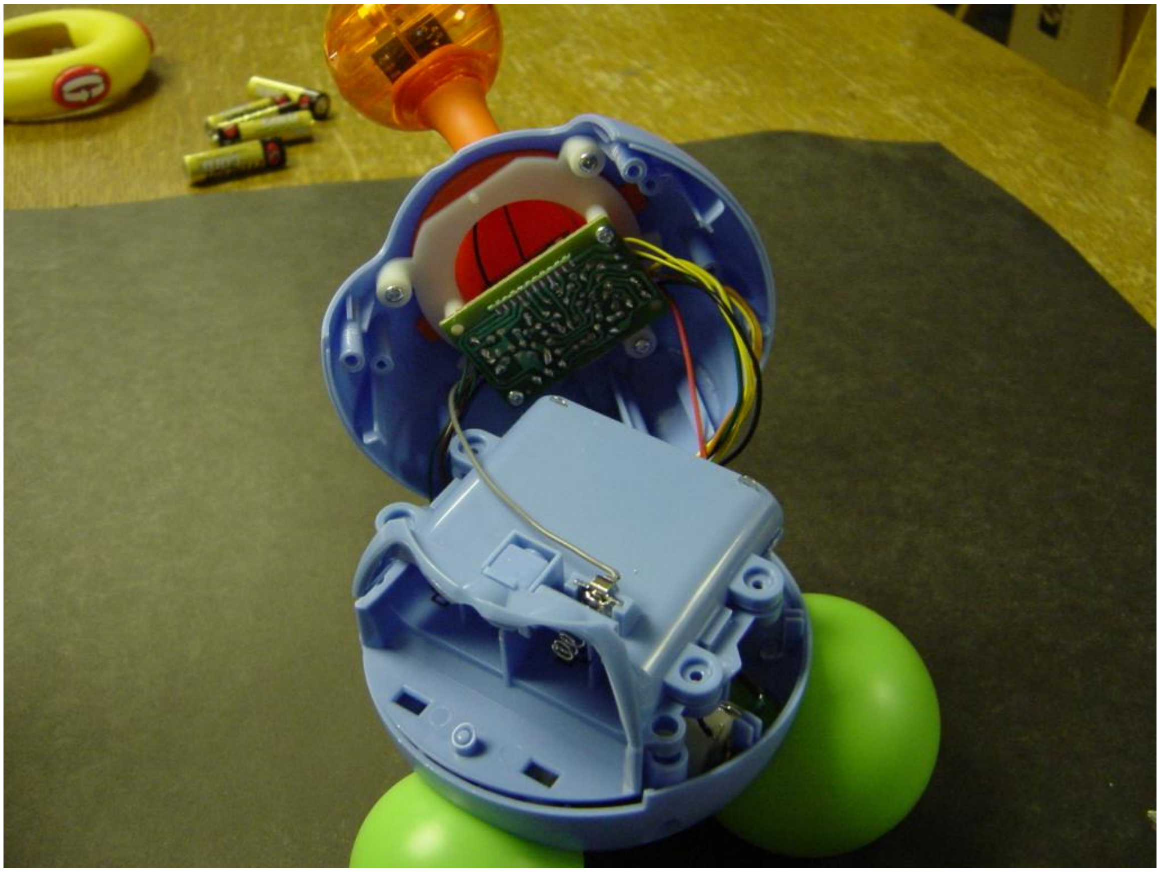


2.1 Goofy Giggles Internals

Goofy Giggles is assembled in three layers. Depending upon the screws removed from the bottom, it is possible to access the electronics, motors, or wheels. Our modifications require accessing only the electronics. The motors are provided with a pair of robust gearboxes along with current limiting resistors:

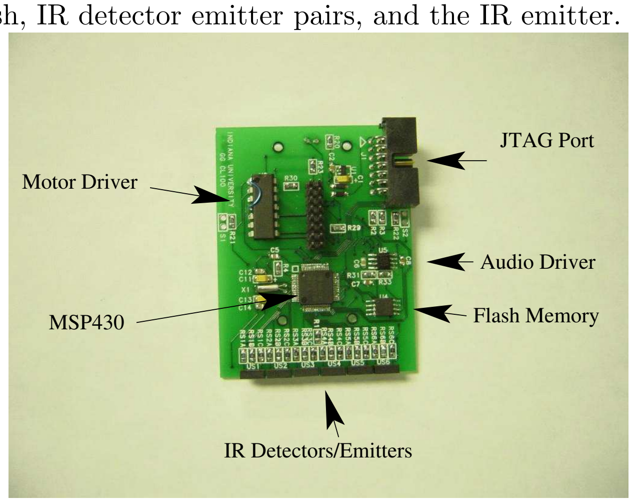


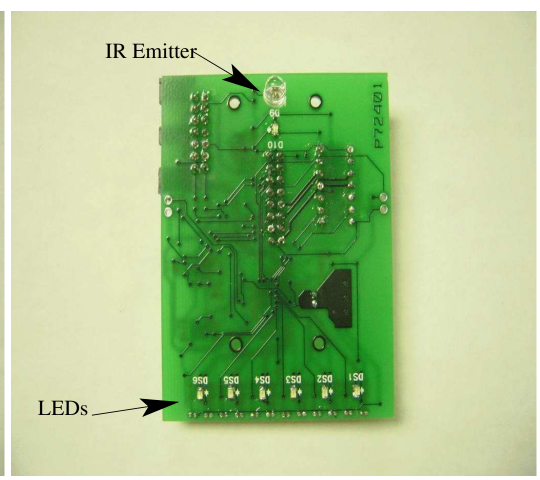
The electronics consist of a single circuit board. In the following picture, this is visible along with the battery box which holds 4 AA batteries.



2.2 A New Brain for Goofy Giggles

The primary circuit board for Goofy giggles is illustrated below. The board is designed so that all components with the exception of the IR emitter and LEDs are sandwiched between the PCB substrate and the mounting bracket. We intend to provide a passivation layer for the exposed portion of the board. The primary components are the processor, audio and motor drivers, serial flash, IR detector emitter pairs, and the IR emitter.





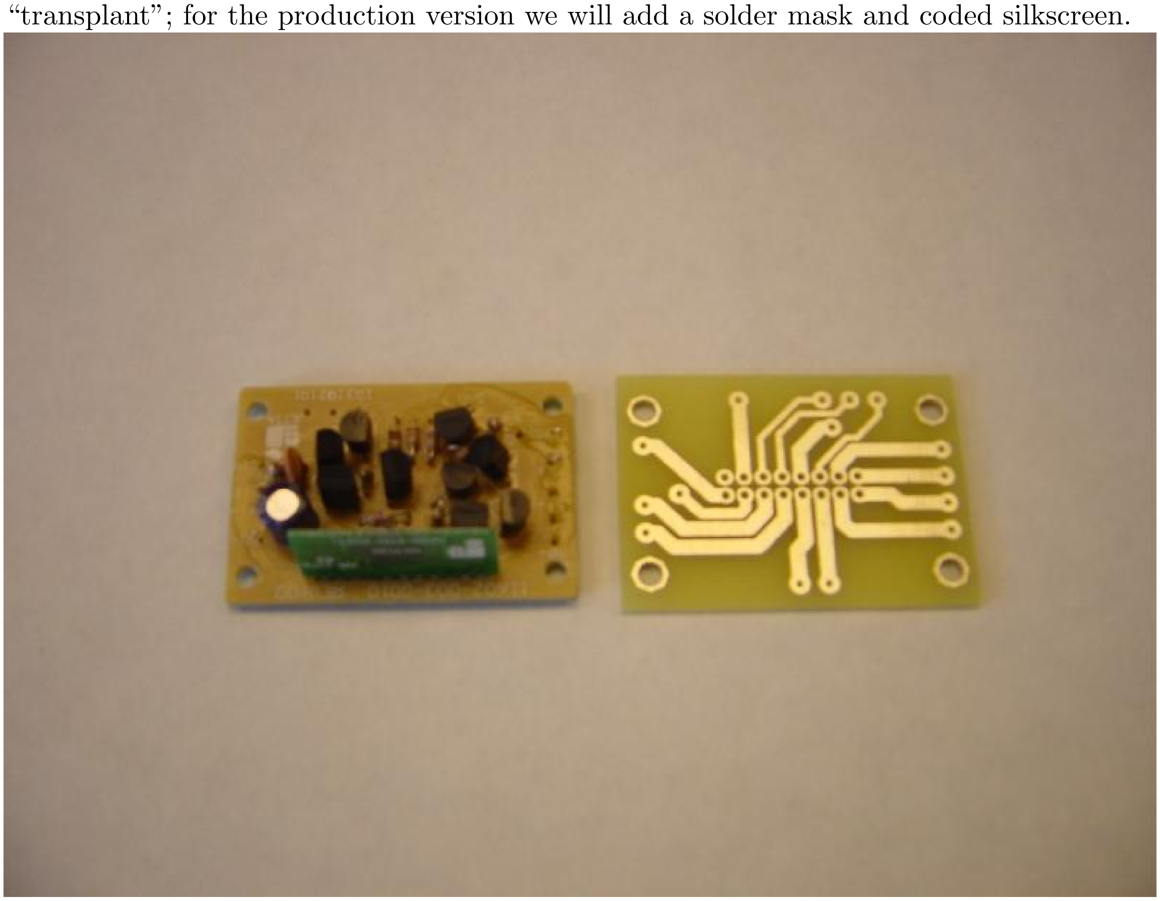
The processor is an MSP430F169 which has roughly 60K flash and 2K ram. In the future a component with 10K ram will be available in the same package; this will enable experiments involving multiple execution threads. The audio driver provides an amplifier which matches the output of the D/A converter (on the processor) with the speaker of of Goofy giggles. The motor driver provides a pair of low dropout H-bridges to enable the processor to independently control the direction of the two motors; speed control will be through PWM. The IR detectors/emitters form a row of six pairs which are interfaced to the processor A/D converter. In addition, a set of six matching LEDs are provided which can be used for visual feedback to enable the debugging of line detection code. The serial flash memory is intended for use as a DMA source or destination for experiments involving downloading and playing music as well as data logging. It is interfaced the the SPI port of the MSP430 and is supported by the DMA controller on the MSP430. The IR emitter is provided for possible use in communication experiments between robots.

Finally a, connector is provided to access the JTAG debugging port of the MSP430. This conforms to the connector provided with the TI FET tools and supported by GDB. In addition, we have used two extra pins to provide a serial interface to a UART on the MSP430; we expect to provide an adapter to enable the use of this serial port.

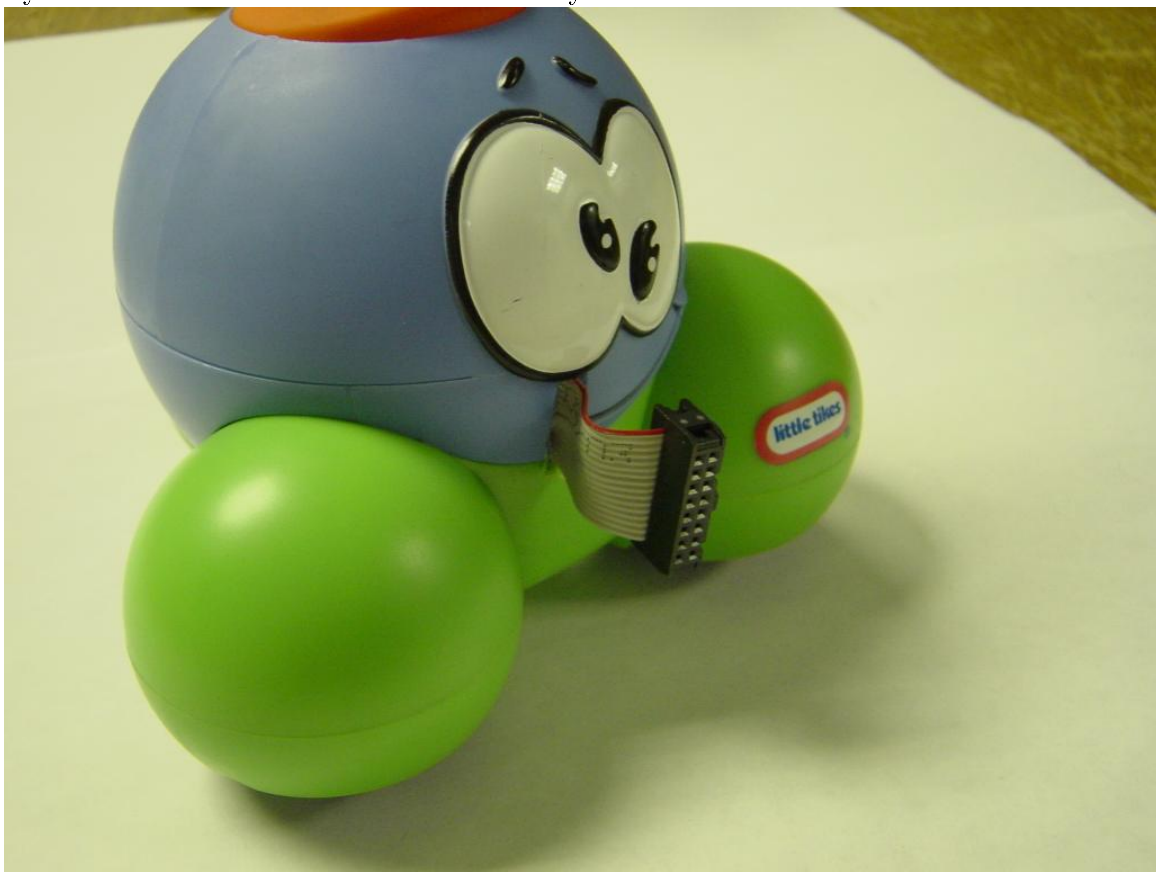
The illustrated board is our first prototype. For production we intend to add a simple battery charger supported by a "wall wart" to enable the use of rechargeable batteries in Goofy Giggles.

2.3 Transplant Operation

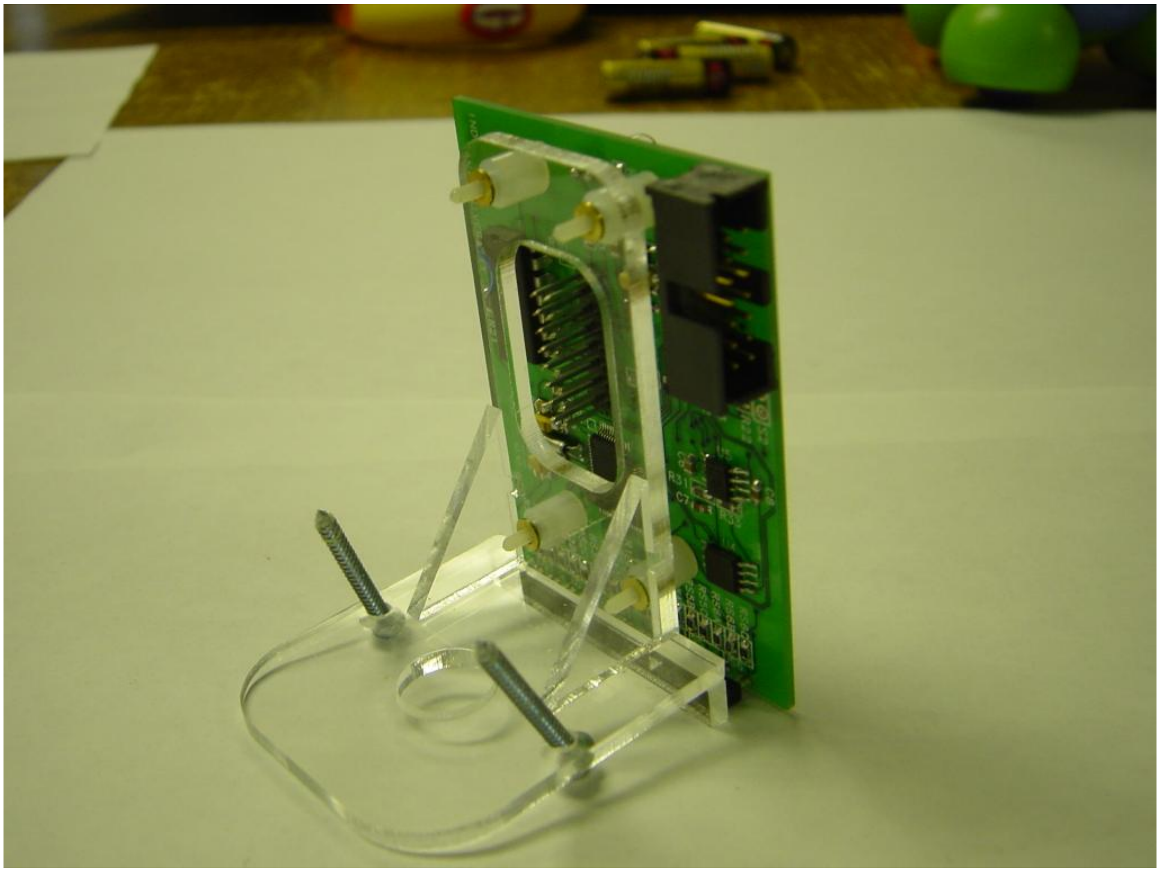
As discussed above, the "new brain" for Goofy giggles is external. We built a small adapter board to replace the internal electronics which connects the existing wires to a single ribbon cable. The design of this board isn't critical; however, we chose to mimic the existing wire layout to simplify the "transplant"; for the production version we will add a solder mask and coded silkscreen.



The ribbon cable is routed through a slit created in Goofy Giggles face. The ribbon cable will be keyed at both ends to ensure correct assembly.



As mentioned previously, the external circuit board is mounted on an acrylic bracket



This bracket was designed to facilitate the use of the existing mounting screw locations on Goofy Giggles

The bracket is produced by a custom laser cutting service for approximately $4/unit. We perform the assembly from the laser cut parts.

3 Proposed Laboratory Experiments

We are currently developing the set of laboratory experiments. We've verified the correct operation of most aspects of our new "brain." The proposed experiments are designed to build toward a final project – line following – and a class time trial (with additional points for "style"). Along the way we want to provide experiments which illustrate various ways to architect such a software system. The list of proposed experiments (along with the expected number of weeks) is given below.

(2) C Tools

- Emacs tutorial
- gcc
- gdb tutorial
- make

(2) C on MSP430

- Simulator: some simple programs, gdb interaction
- Target: compiling for and executing on target
- Buttons and Lights

- Console I/O

(1) Timed programs (polling)

- Sensor scanning
- Playing music
- Motor drive (on/off)

(1) Timed programs (interrupts)

- Cyclic executive
- Decoding IR

(1) Resurrecting Goofy – Write a program to reproduce the standard behavior of Goofy Giggles. A separate music file will be provided.

(1) C/Assembly interface

(1) External Flash

- Flash download/upload program
- Playing music from flash
- Real time event/data logging

(2) DMA, Interrupts, PWM

- Interrupt driven IR decoding
- DMA access to external flash, audio D/A
- Motor speed control with PWM
- Event driven executive
- Event driven goofy

(2) Line Following

- Sensors
- Feedback control
- Debugging using event log
- Competition – time trial plus style points

4 Links

- For a really nice "desk top" line following robot see: http://elm-chan.org/works/ltc/report.html
- A line following competition site: http://www.robotgames.net/RobotGames/Event_Rules/2002_line_follower.htm
- TI MSP430F169 links

  - Main TI page http://focus.ti.com/docs/prod/folders/print/msp430f169.html
  - MSP430F1xx family user's guide http://www-s.ti.com/sc/psheets/slau049d/slau049d.pdf
  - MSP430 gcc toolchain http://mspgcc.sourceforge.net/

- To see what laser cutting arcylic is all about: http://www.pololu.com/laser_cutting.html

5 Acknowledgments

We are grateful to Little Tikes for donating the Goofy Giggles toys required for our laboratory. In addition, we are grateful to TI for providing many of the components.